National Aeronautics and
Space Administration

VIPER

Volatiles Investigating Polar Exploration Rover

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Just Two Decades Ago…

The Moon was a very different place from how we understand it today

Studied from the Earth, in-situ and with samples returned to Earth

The “general” thinking was:

- The surface was relatively constant
- A thin exosphere of Argon, Sodium, Potassium
- ***Bone* dry (~100 ppm of water in soils)**

Toward Understanding Lunar Water

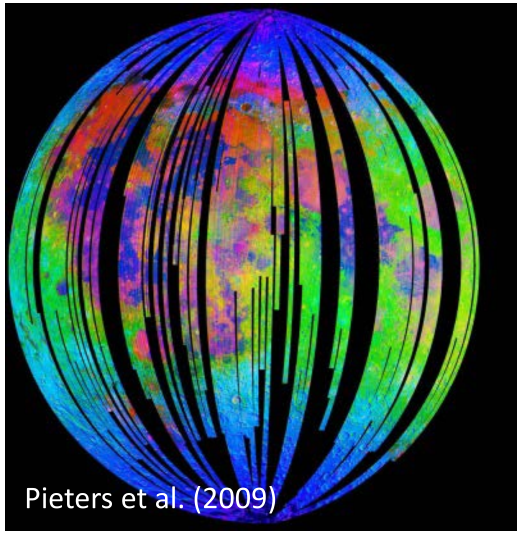
Moon now known to host all three forms of Solar System water: endogenic, sequestered external and in-situ*

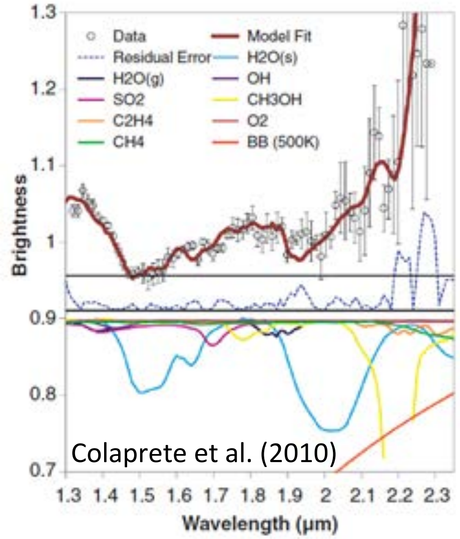
- Do not yet understand the concentration, evolution and interrelated dynamics of these varied sources of water

Understanding the distribution, both laterally and with depth, addresses key exploration and science questions

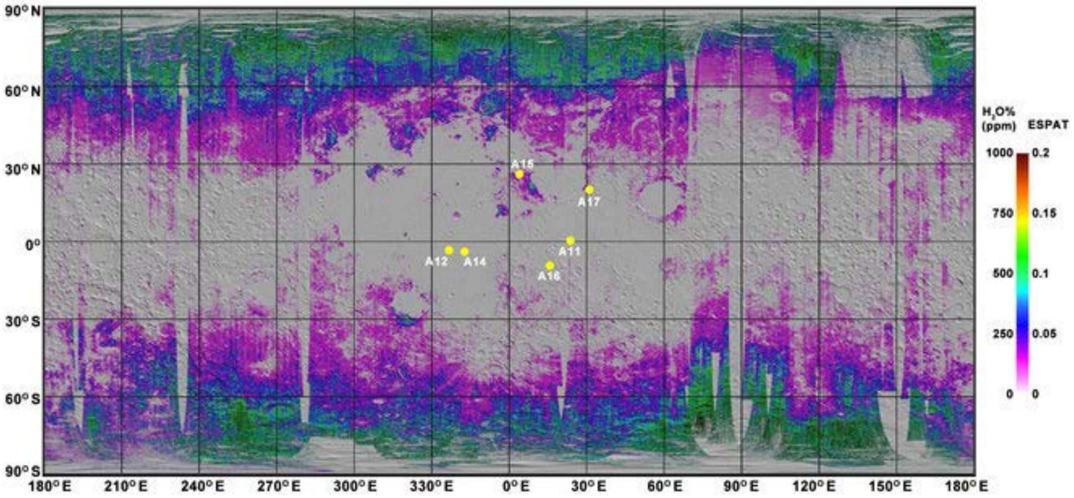
- Surface measurements across critical scales are necessary to characterize the spatial distribution and state of the water

"Prospecting" for lunar water at poles is the next step in understanding the resource potential and addressing key theories about water emplacement and retention


Pieters et al. (2009)



Colaprete et al. (2010)



Li and Milliken (2017)

*From Peters et al. Transformative Lunar Science (2018)

VIPER Mission

Lunar south pole

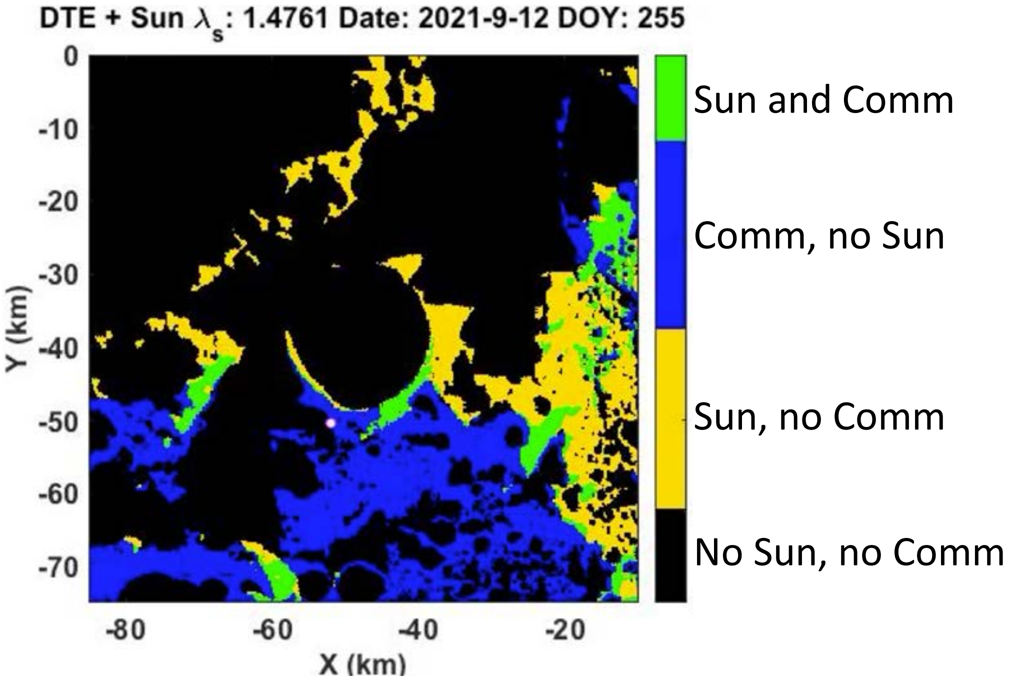
- 11/2023 launch
- 100+ day mission (including extended survival periods)
- Up to 20 km total drive

Science objectives

- Characterize distribution and physical state of volatiles (water ice, etc)
- Provide data to evaluate the potential for lunar in-situ resource utilization

A few unique challenges (among many…)

- Dynamic environment: light + shadows
- Real-time mission ops and science
- Prospecting & “speed made good”



The Big Picture of Lunar Resources

US Lunar Goals:

Orbital Observations → Orbital Prospecting → Ground Truthing → Ground Prospecting → Resource Mapping → ISRU & Mining Demonstrations → Bulk Production

Missions:

Clementine

VIPER

(future science missions)

Lunar Prospector

LCROSS

Industry

LRO

Industry

Chandrayaan-I

VIPER bridges Government and Industry missions – informing and reducing risk for future utilization of in-situ volatiles

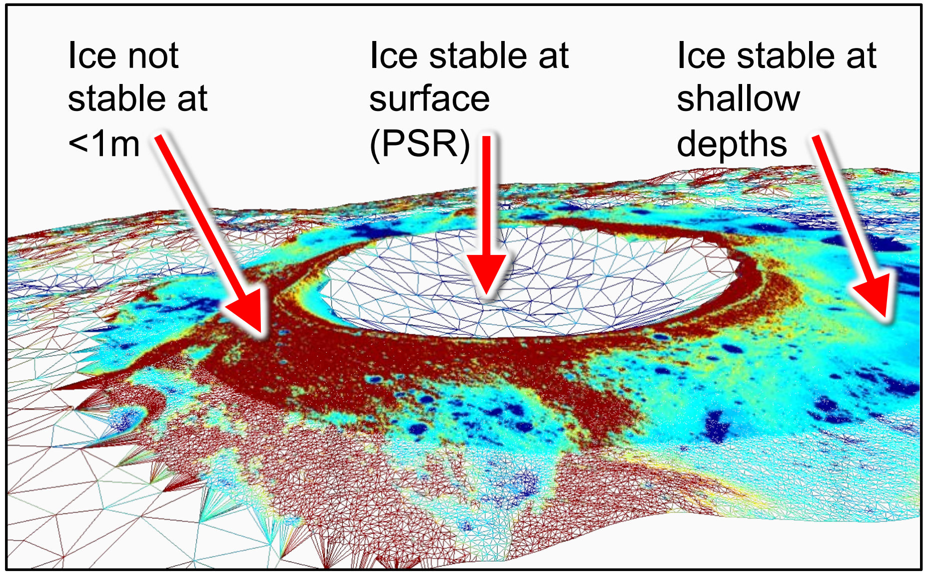
Where is water (ice) at the lunar poles?

Environmental factors

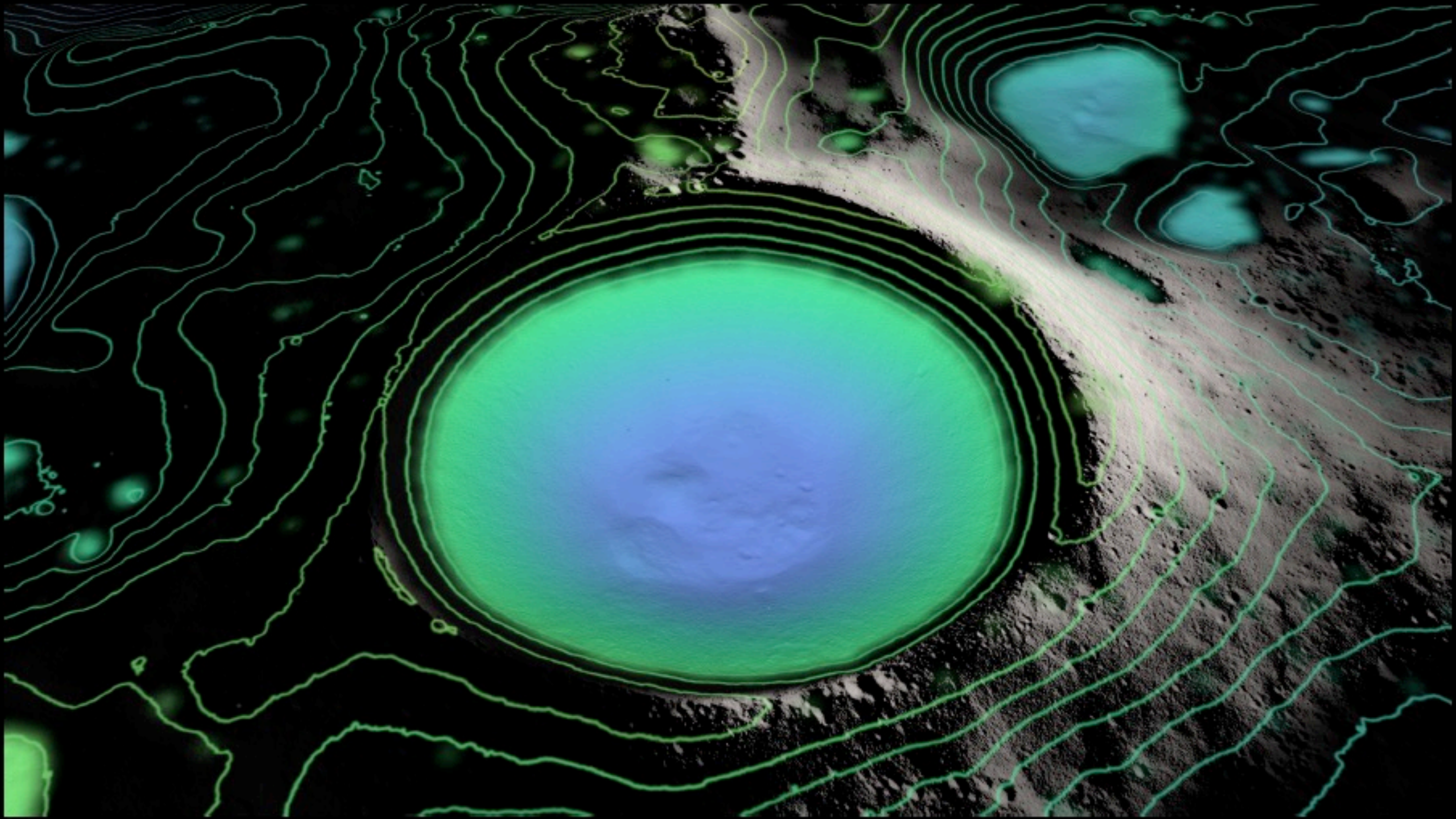
- Temperatures (surface or subsurface) must be low enough to retain water ice
- Geophysical properties (topography, materials, depth, etc.)

Ice Stability Regions

- **Dry**: Temperatures in the top meter expected to be too warm for ice stability
- **Deep**: Ice expected to be stable between 50-100 cm of the surface
- **Shallow**: Ice expected to be stable within 50cm of surface
- **Surface**: Ice expected to be stable at the surface (e.g., within a Permanently Shadowed Region or "PSR")



Permanently Shadowed Regions on the Moon

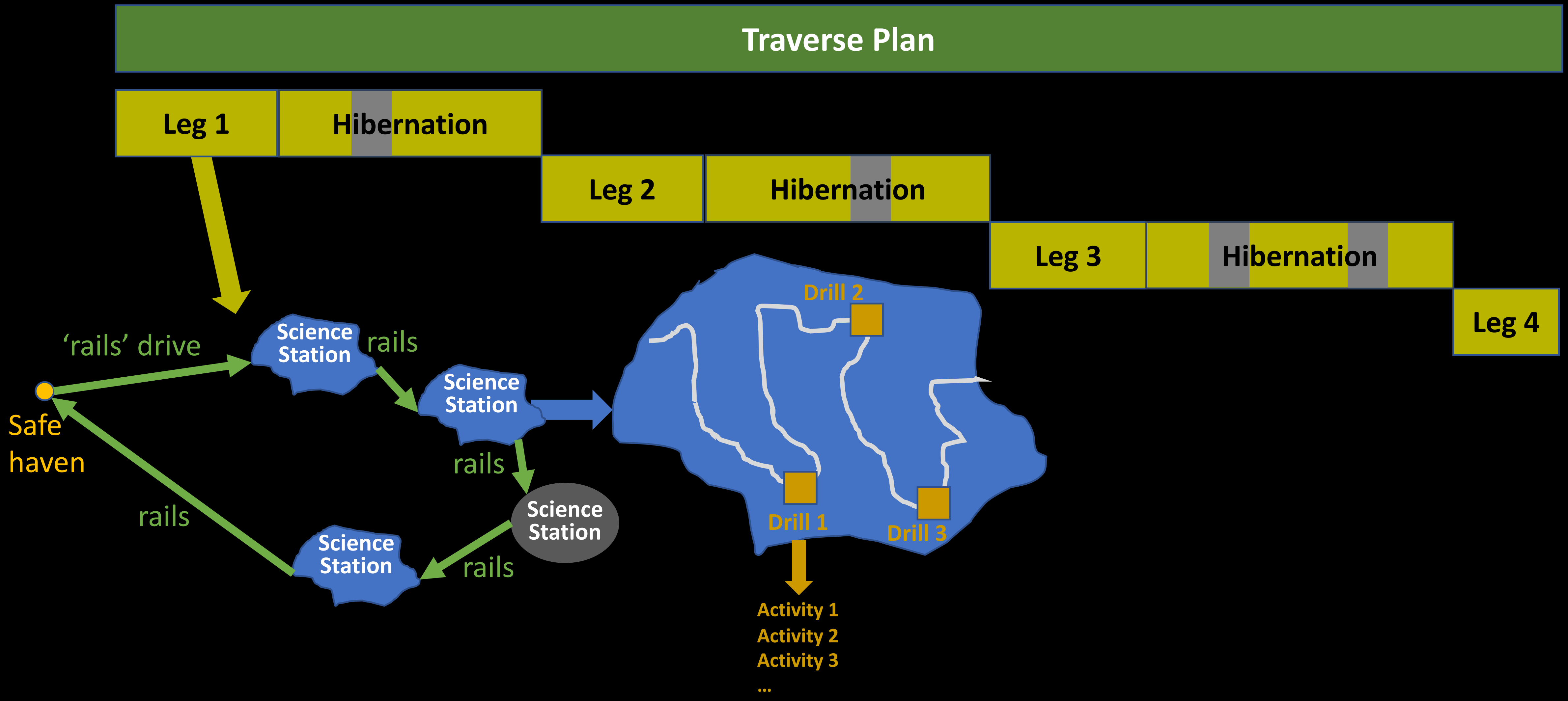


NASA SVS

- Low obliquity.
- At high latitudes, topography creates permanently shadowed regions.
- $>10^4$ km^2 area of PSR.
- These exist on size scales ranging from sub-mm to 10 km.

https://svs.gsfc.nasa.gov/4043

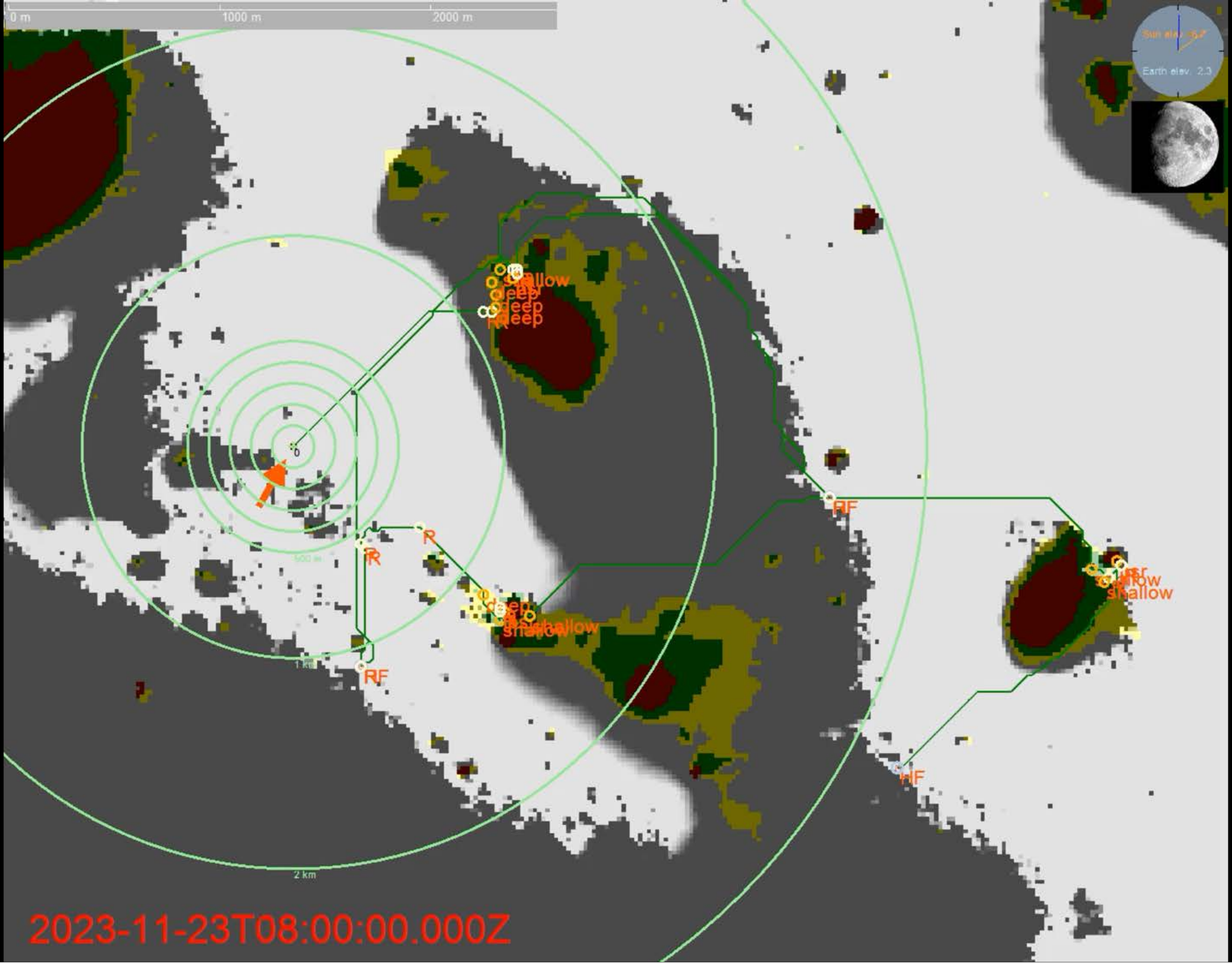
VIPER Surface Mission

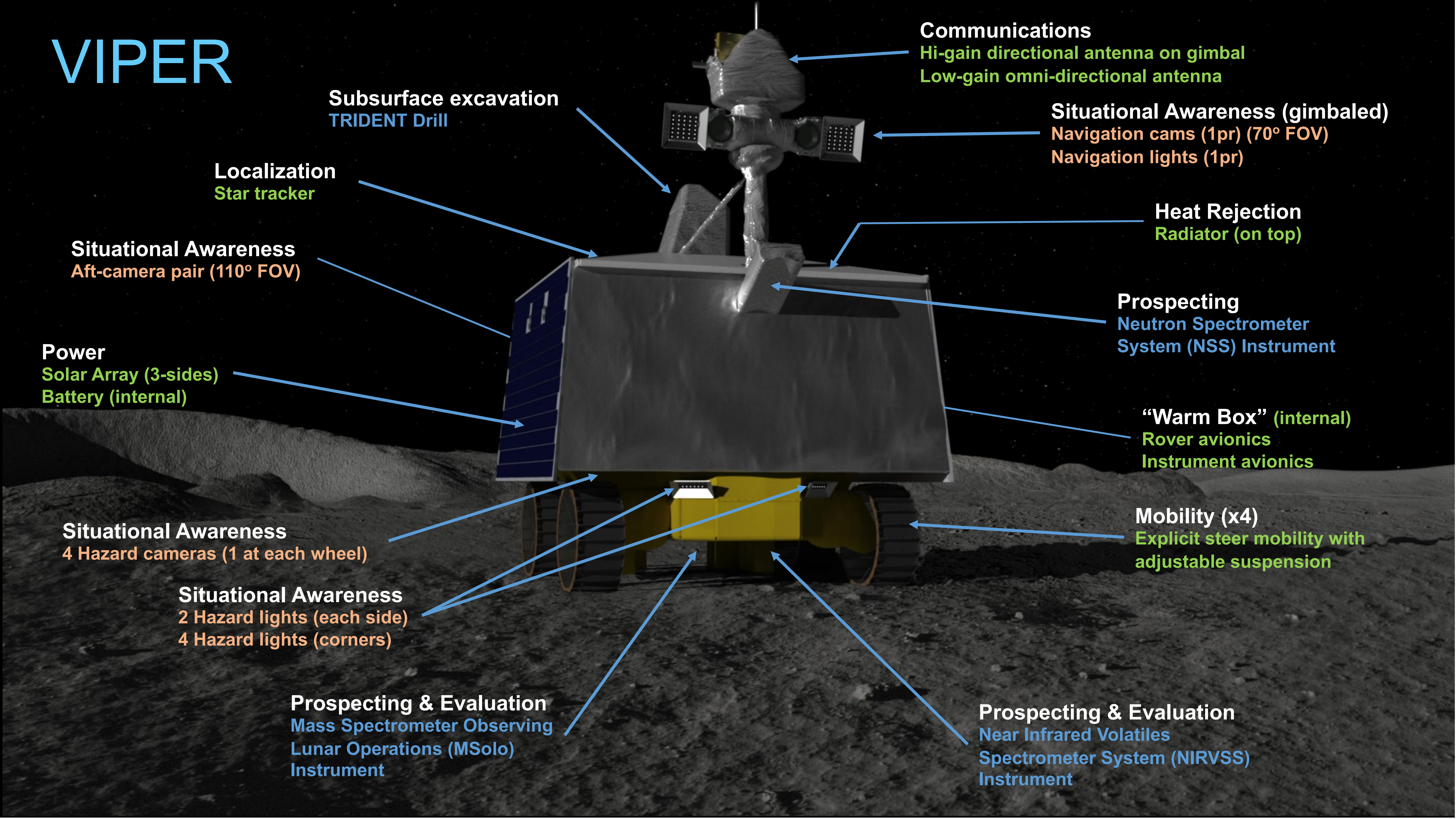


Nobile A Traverse Plan *(notional)*

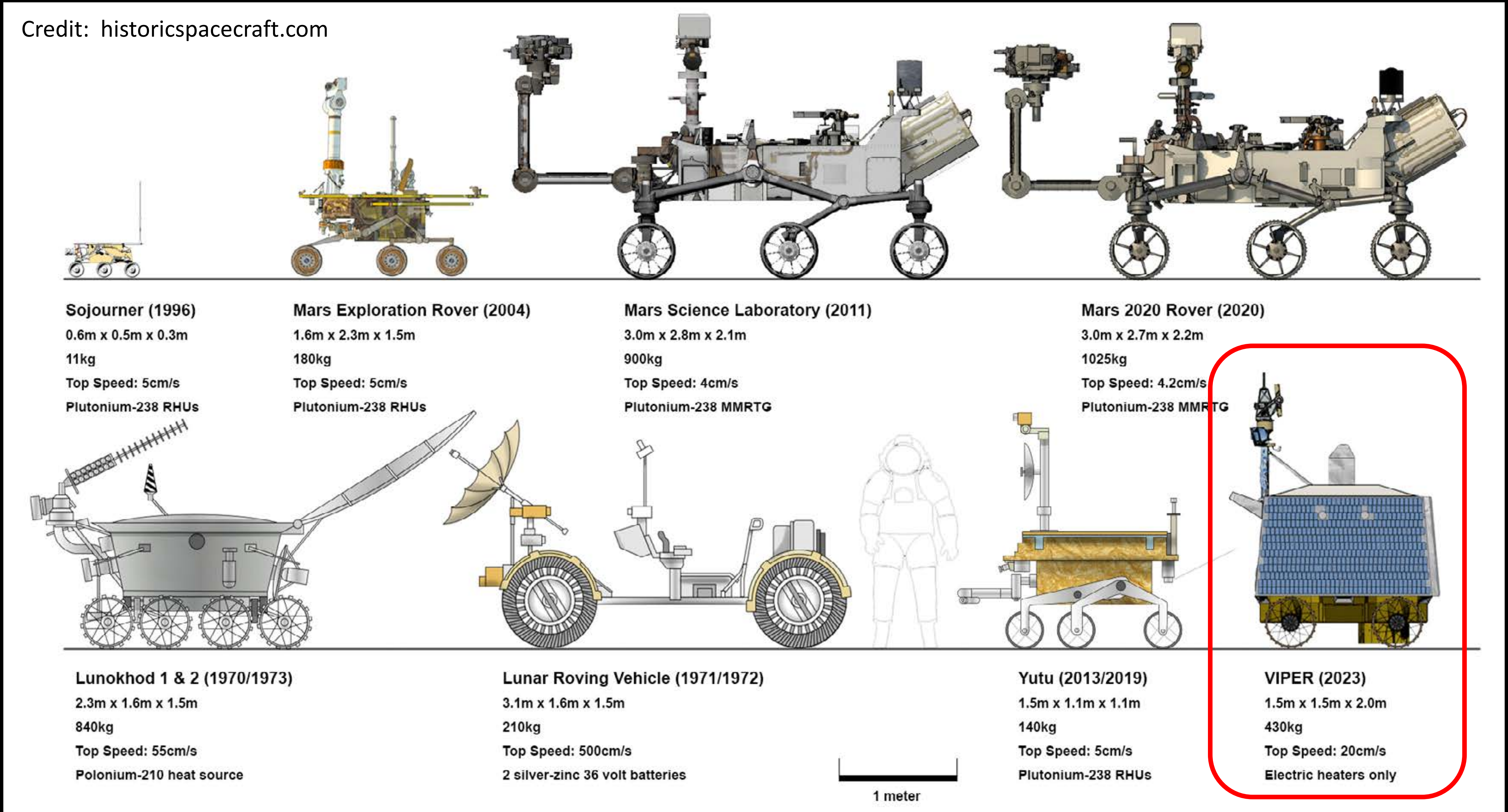
2023-11-23
to
2024-03-07

106 days




VIPER
Subsurface excavation
TRIDENT Drill
Communications
Hi-gain directional antenna on gimbal
Low-gain omni-directional antenna
Situational Awareness (gimbaled)
Navigation cams (1pr) (70º FOV)
Navigation lights (1pr)
Localization
Star tracker
Heat Rejection
Radiator (on top)
Situational Awareness
Aft-camera pair (110º FOV)
Prospecting
Neutron Spectrometer
System (NSS) Instrument
Power
Solar Array (3-sides)
Battery (internal)
“Warm Box” (internal)
Rover avionics
Instrument avionics
Mobility (x4)
Explicit steer mobility with
adjustable suspension
Situational Awareness
4 Hazard cameras (1 at each wheel)
Situational Awareness
2 Hazard lights (each side)
4 Hazard lights (corners)
Prospecting & Evaluation
Mass Spectrometer Observing
Lunar Operations (MSolo)
Instrument
Prospecting & Evaluation
Near Infrared Volatiles
Spectrometer System (NIRVSS)
Instrument

Rover Comparison



VIPER Rover

Mass: approx. 490 kg

- Rover, instruments, and lander release

Dimensions

- Approx. 1.8m x 1.8m x 2.6m (L x W x H)
- 0.5 m wheel diameter

Mobility: 4 wheels with adj. suspension

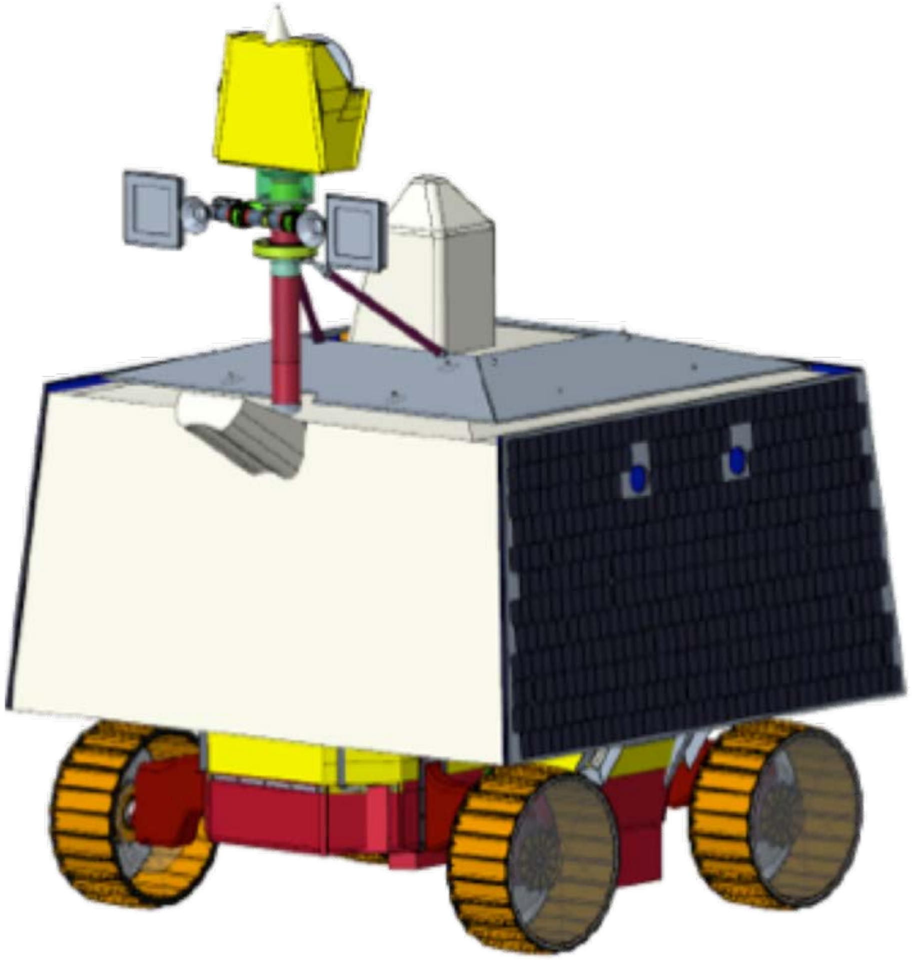
- 10-20 cm/s with 20 km range
- 20 cm obstacles, 15 deg slopes

Power: approx. 450W (peak)

- Solar arrays (sides + aft) & batteries

Comm: X-band “Direct to Earth” (DTE)

- 256 kbps downlink, 2 kbps uplink
- 6-10 sec round-trip delay



Key Mobility Requirements

Level 2

- Traverse a path on the lunar surface of at least 20 km
- Traverse at a speed of no greater than 10 cm/s while prospecting
- Traverse at speeds of up to 20 cm/s to provide a "sprint" capability

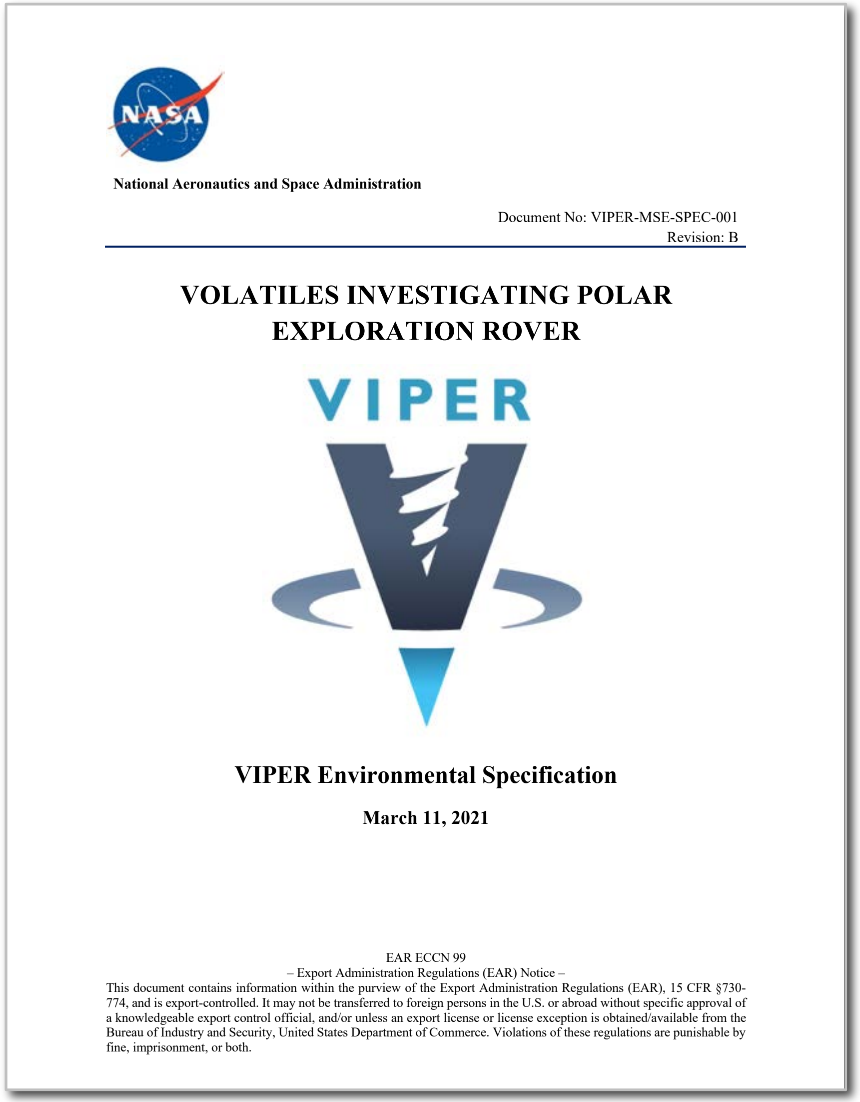
Level 3

- No more than 40% slip on slopes of up to ±15 deg
- No more than 10% side-slip on slopes of up to ±15 deg
- Traverse obstacles of up to 10 cm in height on slopes of up to ±15 deg with wheel speed of 20 cm/s
- Traverse obstacles of up to 20 cm in height on slopes of up to ±10 deg
- Provide the Rover with a nominal ground clearance of at least 25 cm
- Drive waypoints while maintaining a heading within 2 deg under zero slip
- Maintain body attitude with ±5 deg

VIPER Environmental Specification

Key Sections for Mobility

- Lunar Soil Physical Properties
  - Particle-level
  - Bulk-level
  - Electrical
  - Thermal
  - Dust
- Rock and Crater Properties
  - Size and frequency
  - Spatial distribution
- Slope Properties
  - Inter-crater
  - Traverse



National Aeronautics and Space Administration

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Revision: B

VOLATILES INVESTIGATING POLAR EXPLORATION ROVER

VIPER

VIPER Environmental Specification

March 11, 2021

EAR ECCN 99
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Mobility Architecture

Independent Wheel Modules (4x)

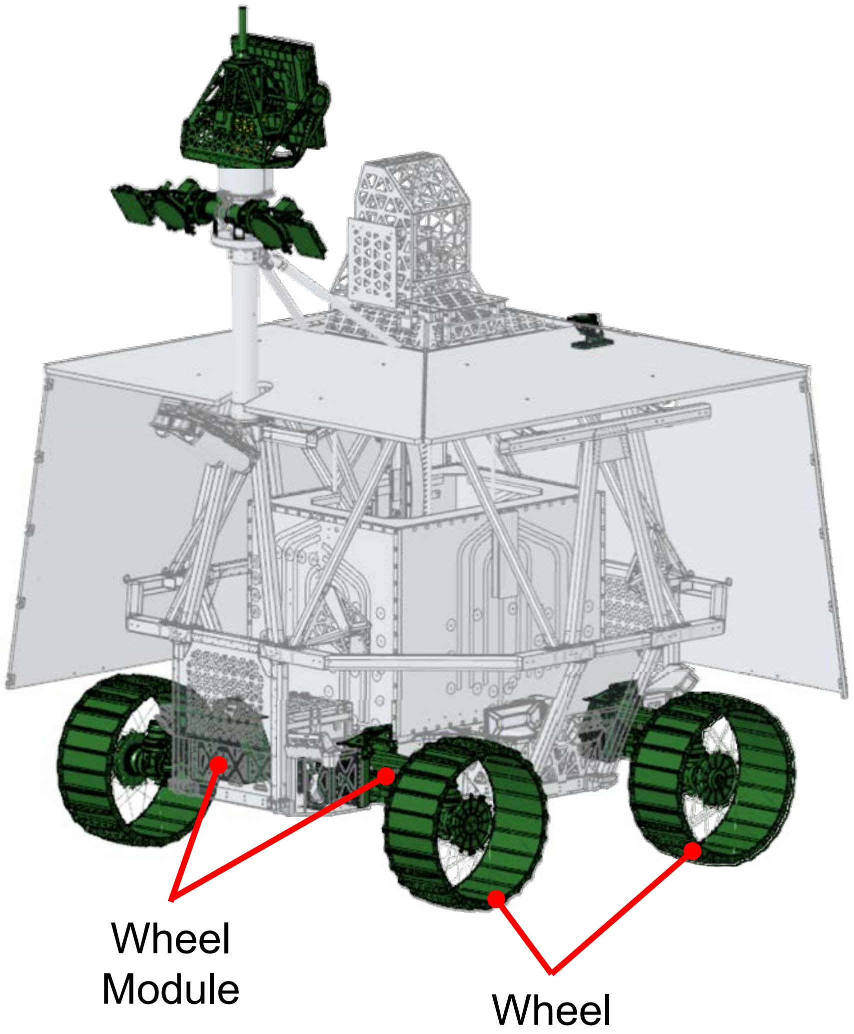
- Suspension
- Steering
- Propulsion

Wheels (4x)

- 50 cm diameter, 20 cm wide
- Rigid sheet metal with spokes
- Rim grousers

Capabilities

- Actuated suspension enables body attitude and clearance control
- Explicit steering (with sufficient torque to perform skid steering)
- Alternate mobility (e.g., “inchworming”)



Independent Steering

Offset steering axis

- Reduces wheel scrub
- Reduces risk of embedding
- Allows for point turns

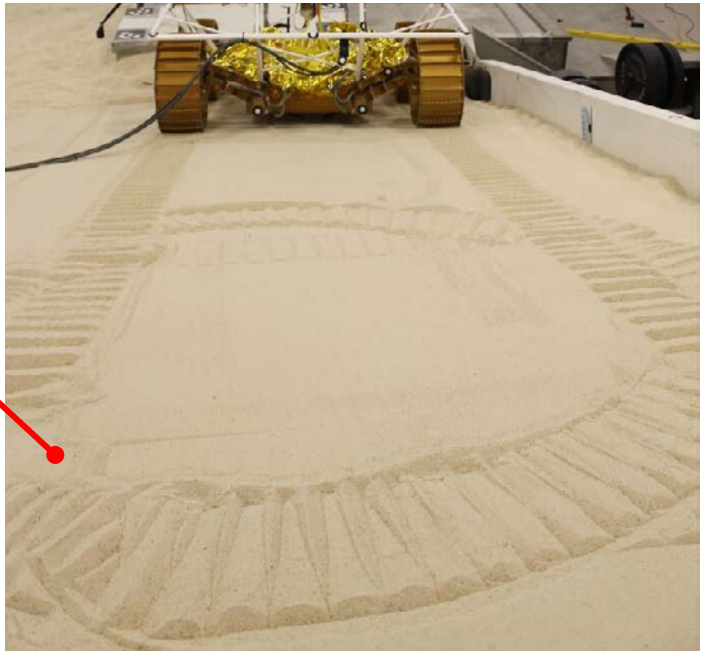
Wide steering range (> ±45 deg)

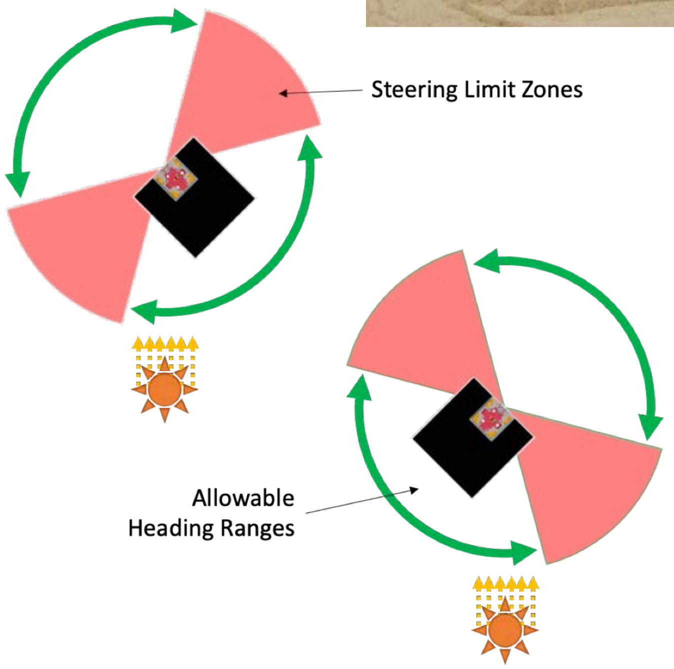
- Enables near-holonomic motion
- Allows the rover to translate in almost any direction while also maintaining optimal exposure of the solar arrays

Limitations

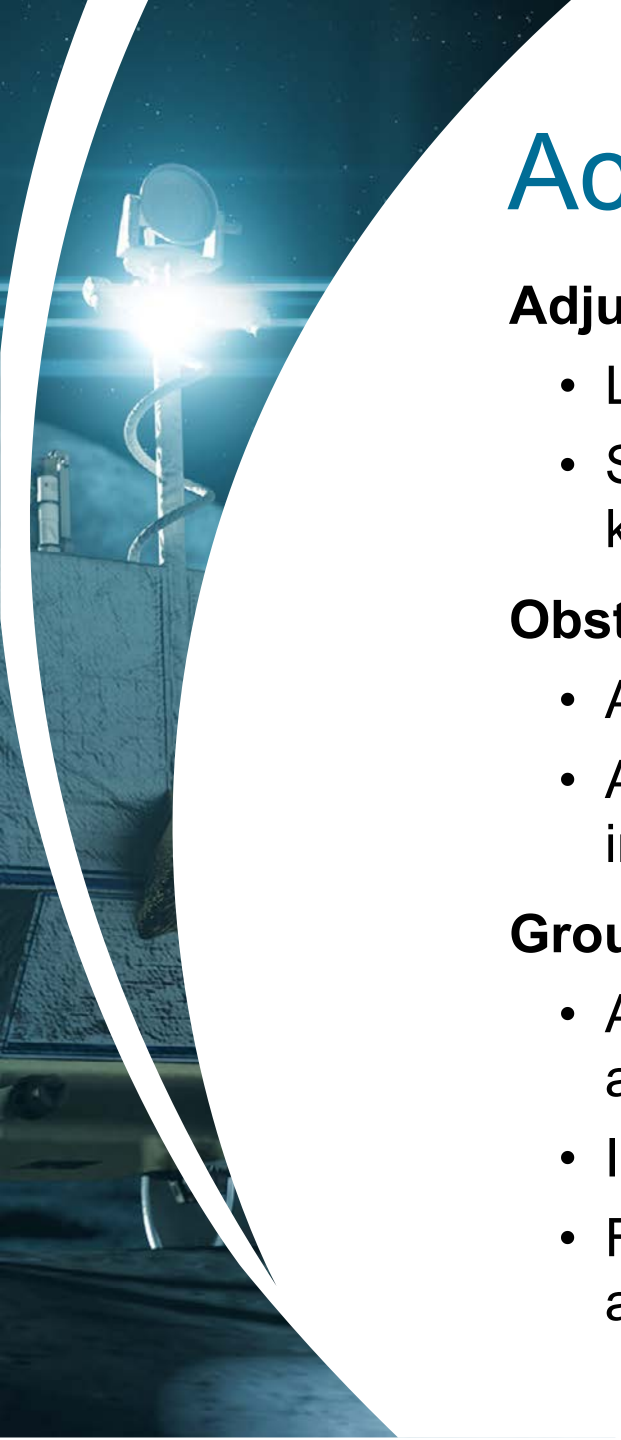
- More complex than skid steering
- High actuator & part count

No “scrub piling”





Actuated Suspension



Adjustable (not active)

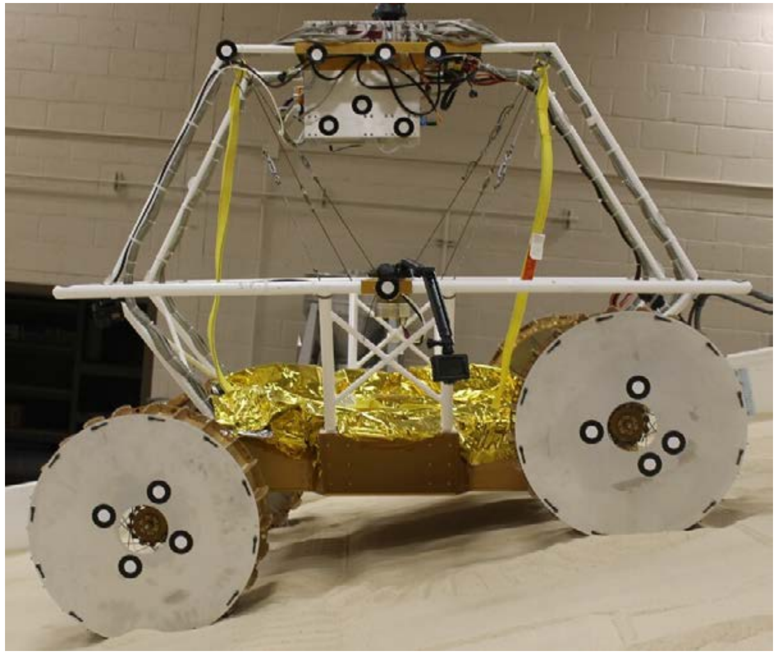
- Low control cycle (10 Hz)
- Suitable for low-speed, primarily kinematic (non-dynamic) motion

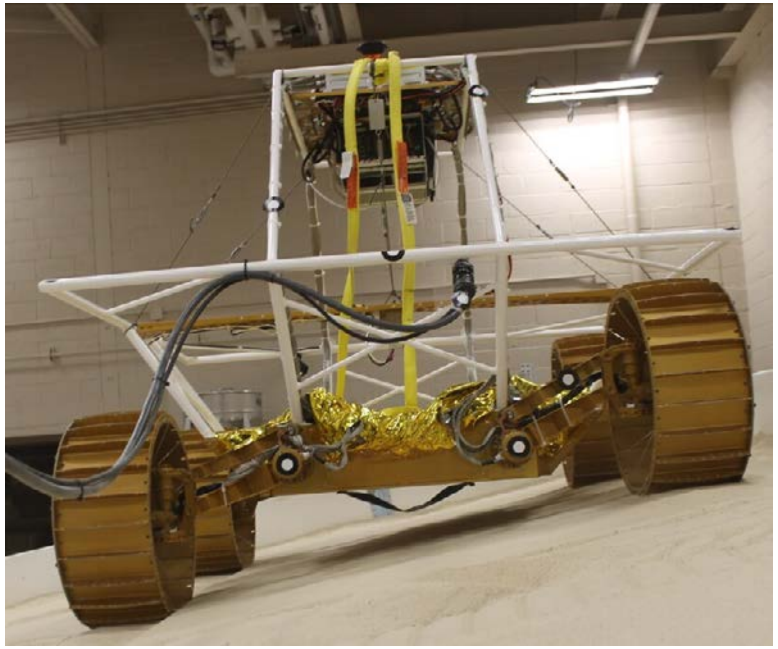
Obstacle & slope climbing

- Articulation increases stability margin
- Articulation and body attitude control improves cross-slope trafficability

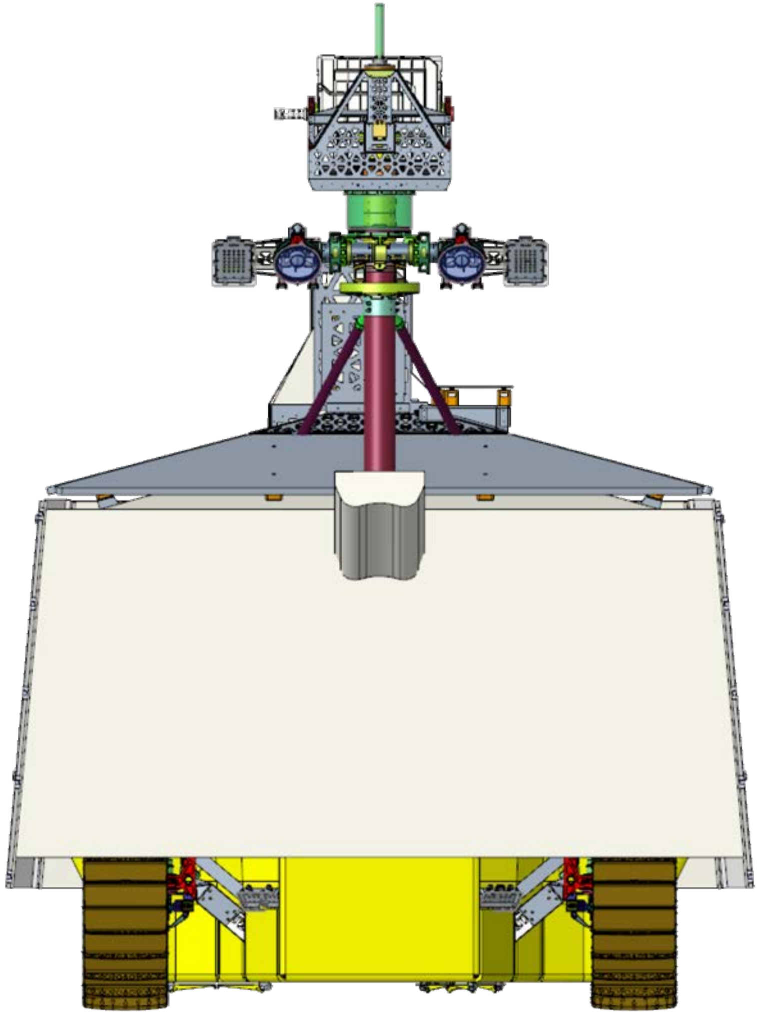
Ground clearance

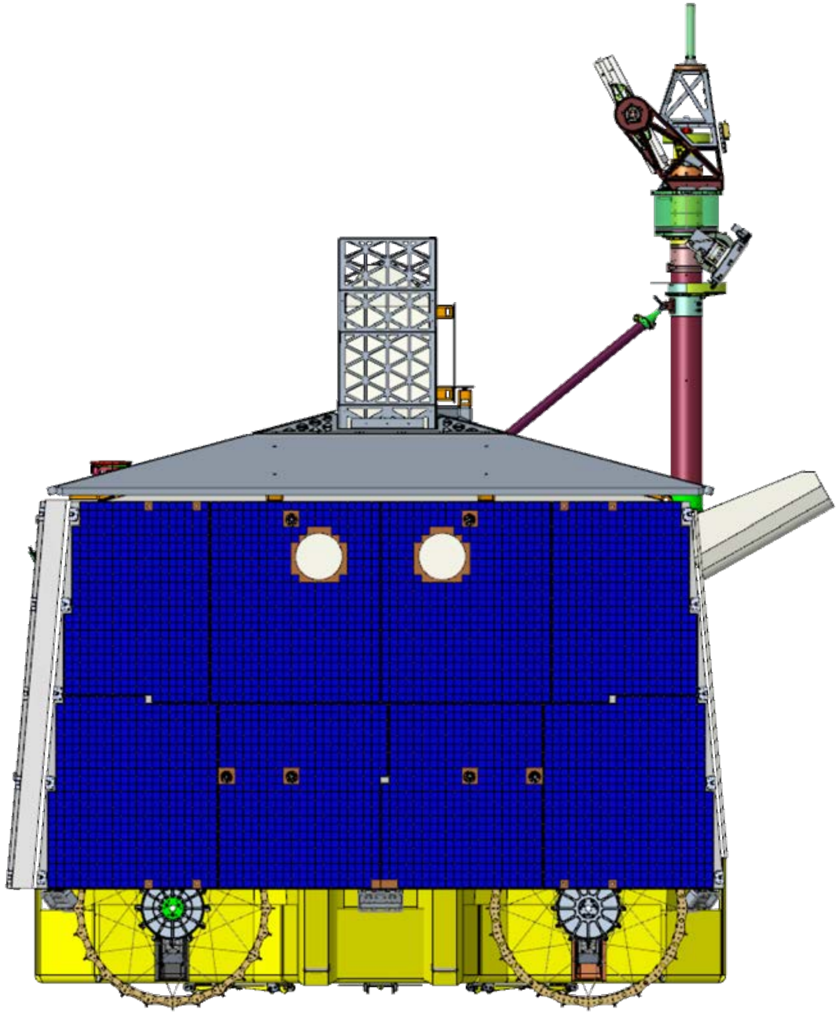
- Adjustable ride height reduces collision and high-centering risk
- Increases egress flexibility
- Facilitates drill positioning and alignment control





Suspension Travel





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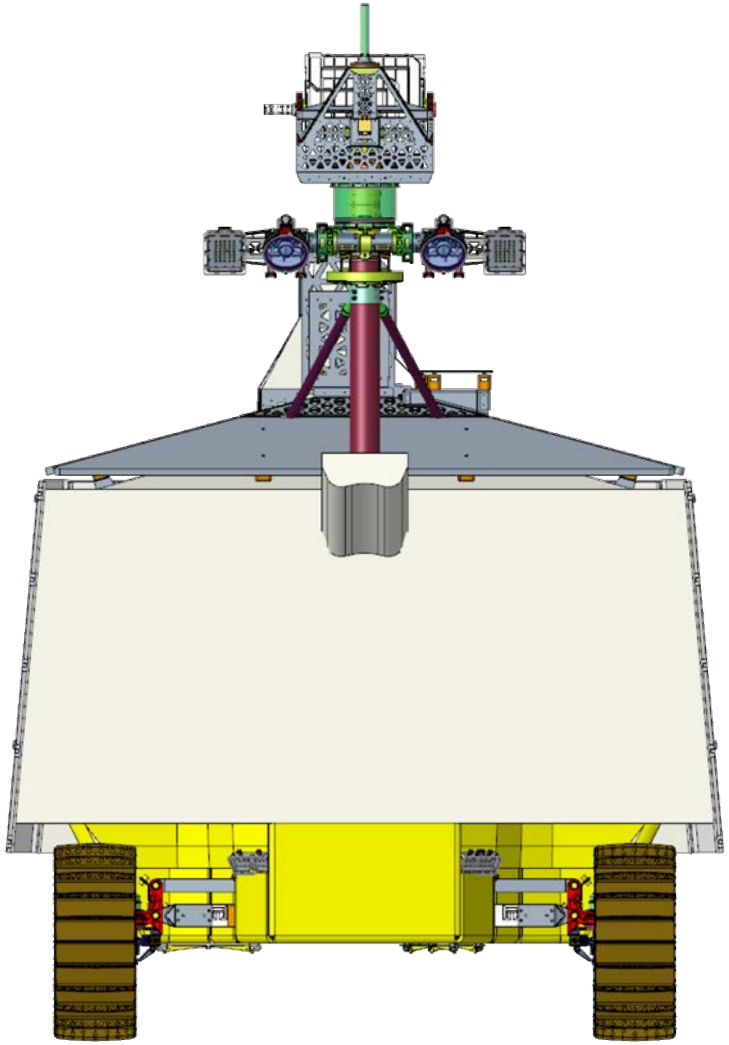
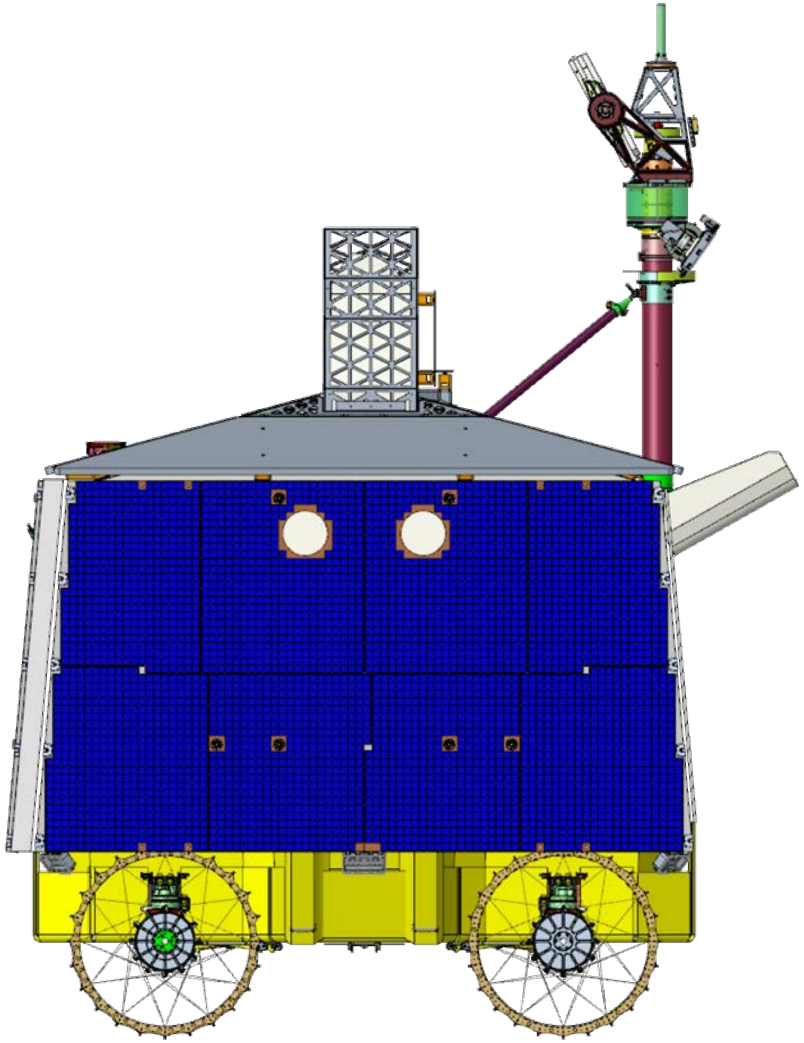
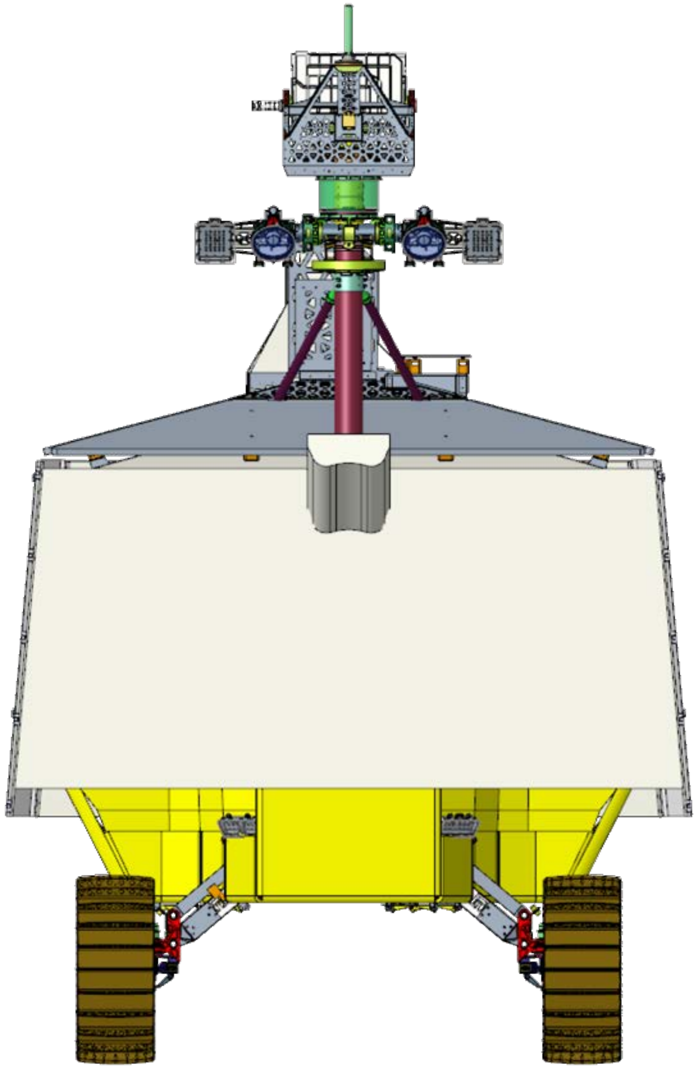
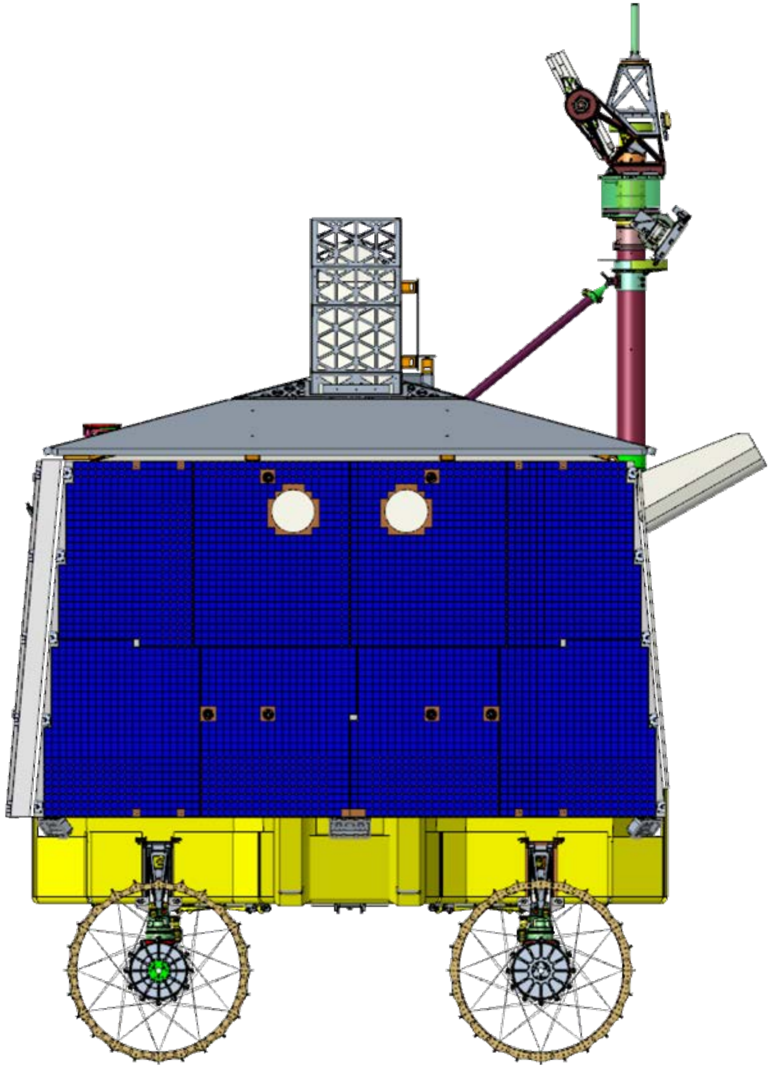




Suspension Travel

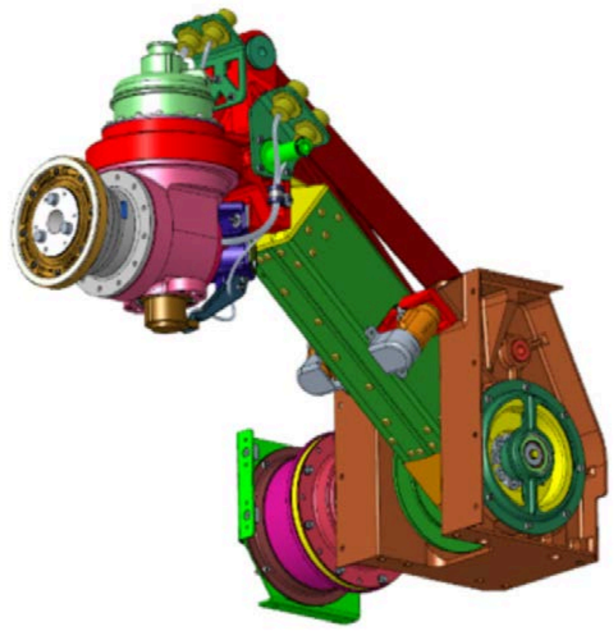


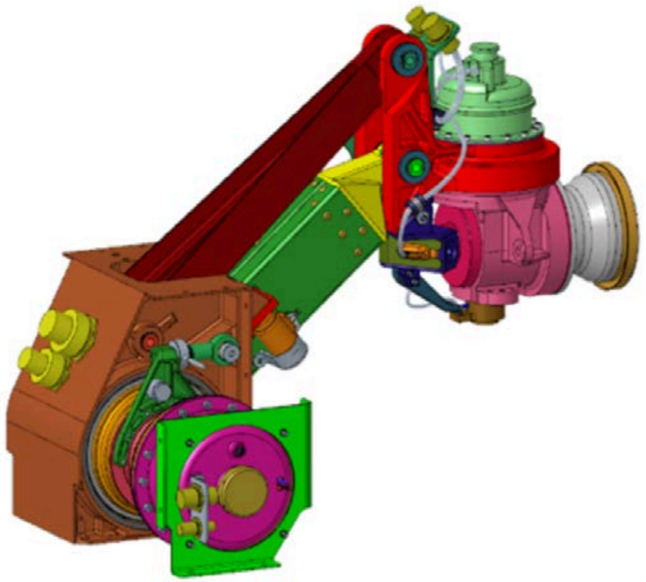


Actuators

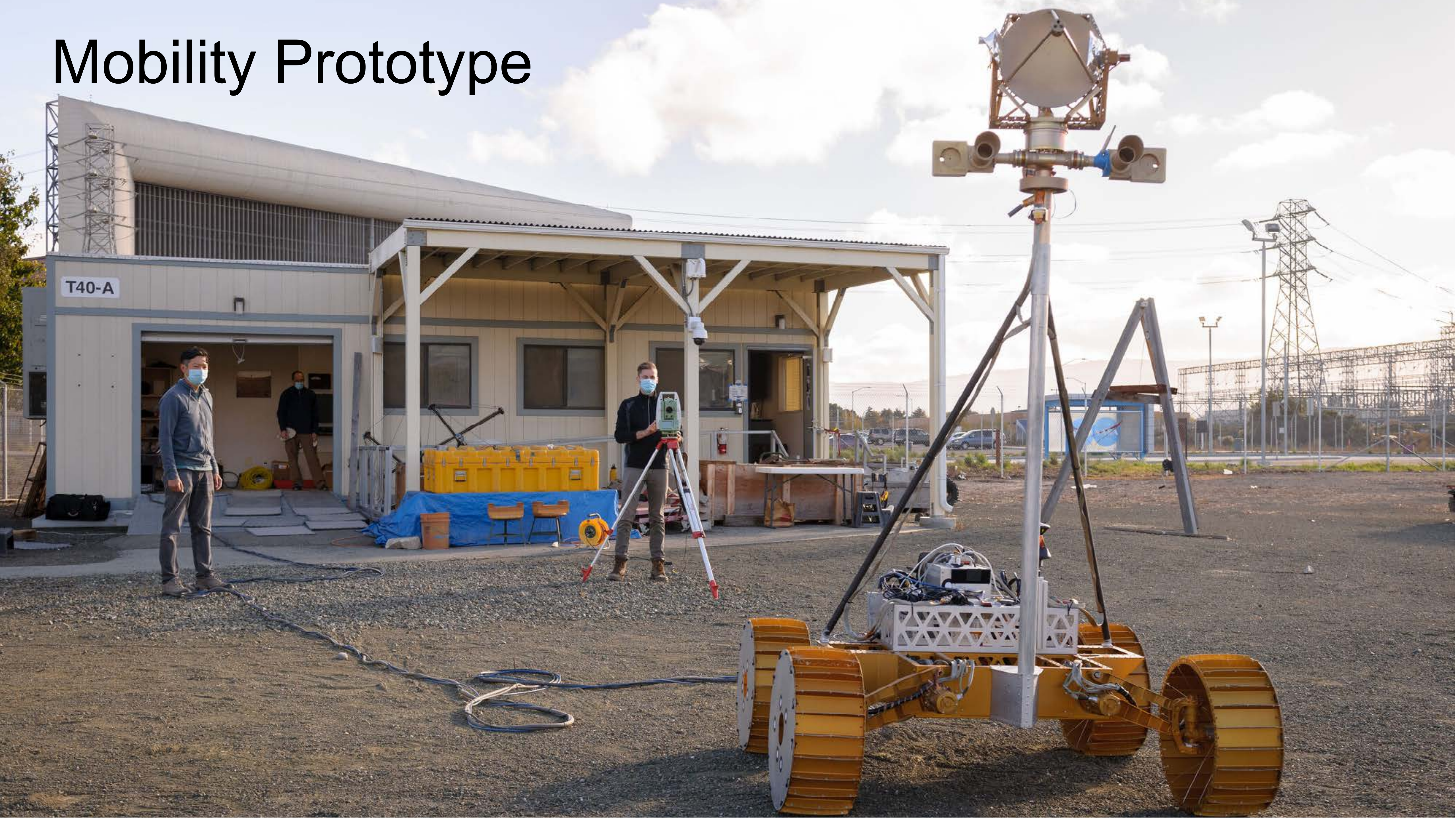
Key Characteristics

- Suspension, steering, and propulsion actuators at each wheel module.
- Brushless DC motors with resolvers for commutation and joint output angles.
- Propulsion utilizes planetary gear stage.
- Steering and Suspension utilizes a strain wave (harmonic) gear reduction.
- Suspension utilizes a mechanical anti-backdrive device.
- Suspension equipped with a load cell for downforce measurement.
- Actuators operate down to -50 C and survive to -200 C.

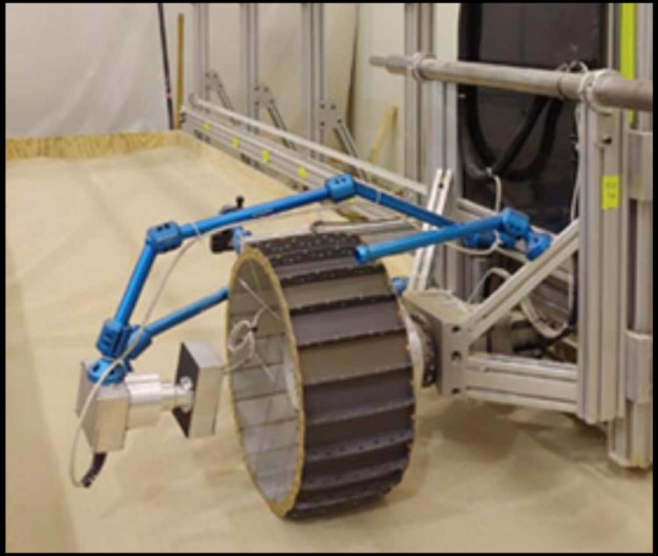


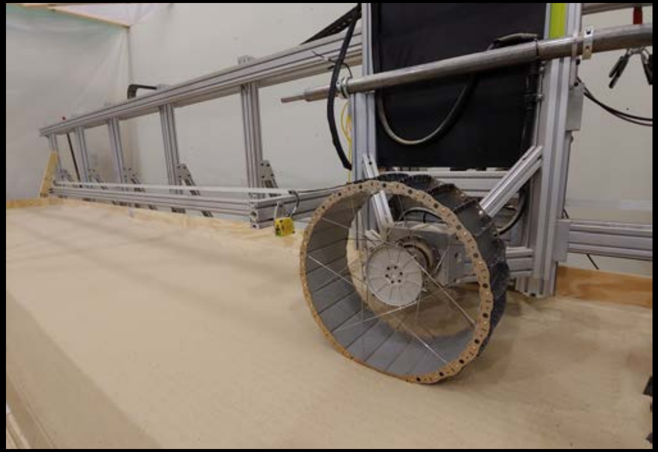


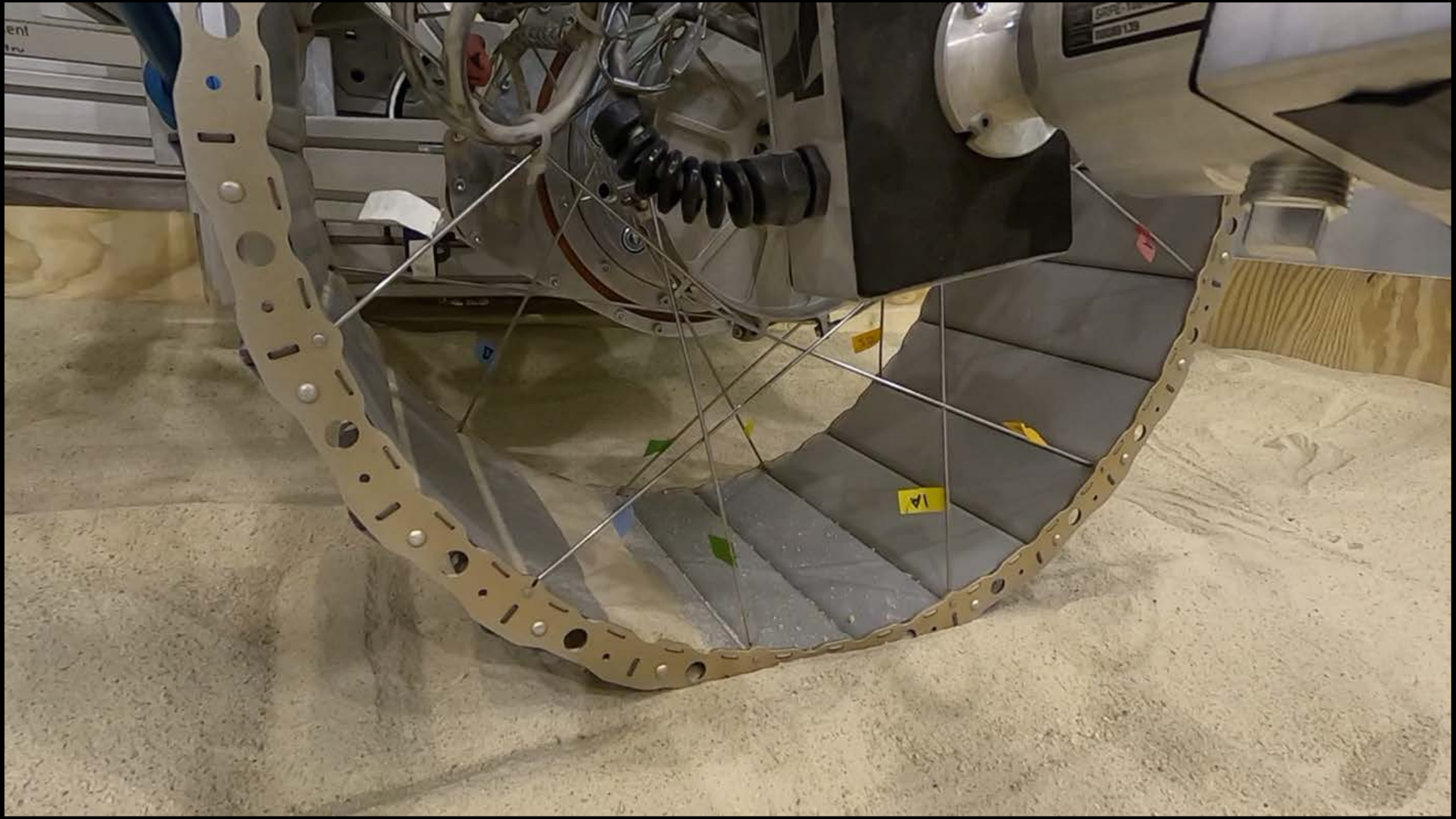
Mobility Prototype



Wheel Prototype Testing

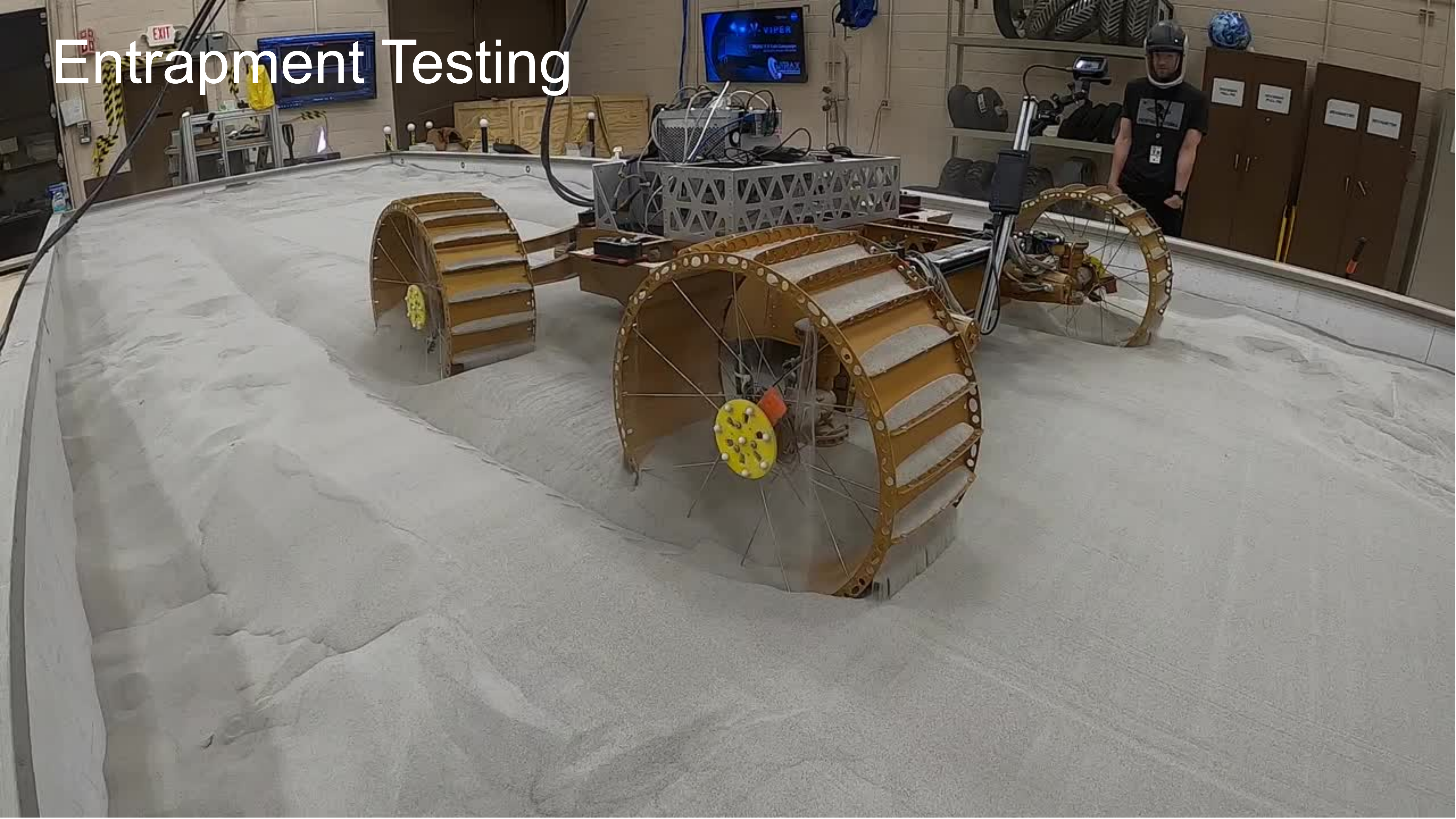






Characterization and endurance testing performed by ProtoInnovations, LLC (Pittsburgh)

Entrapment Testing

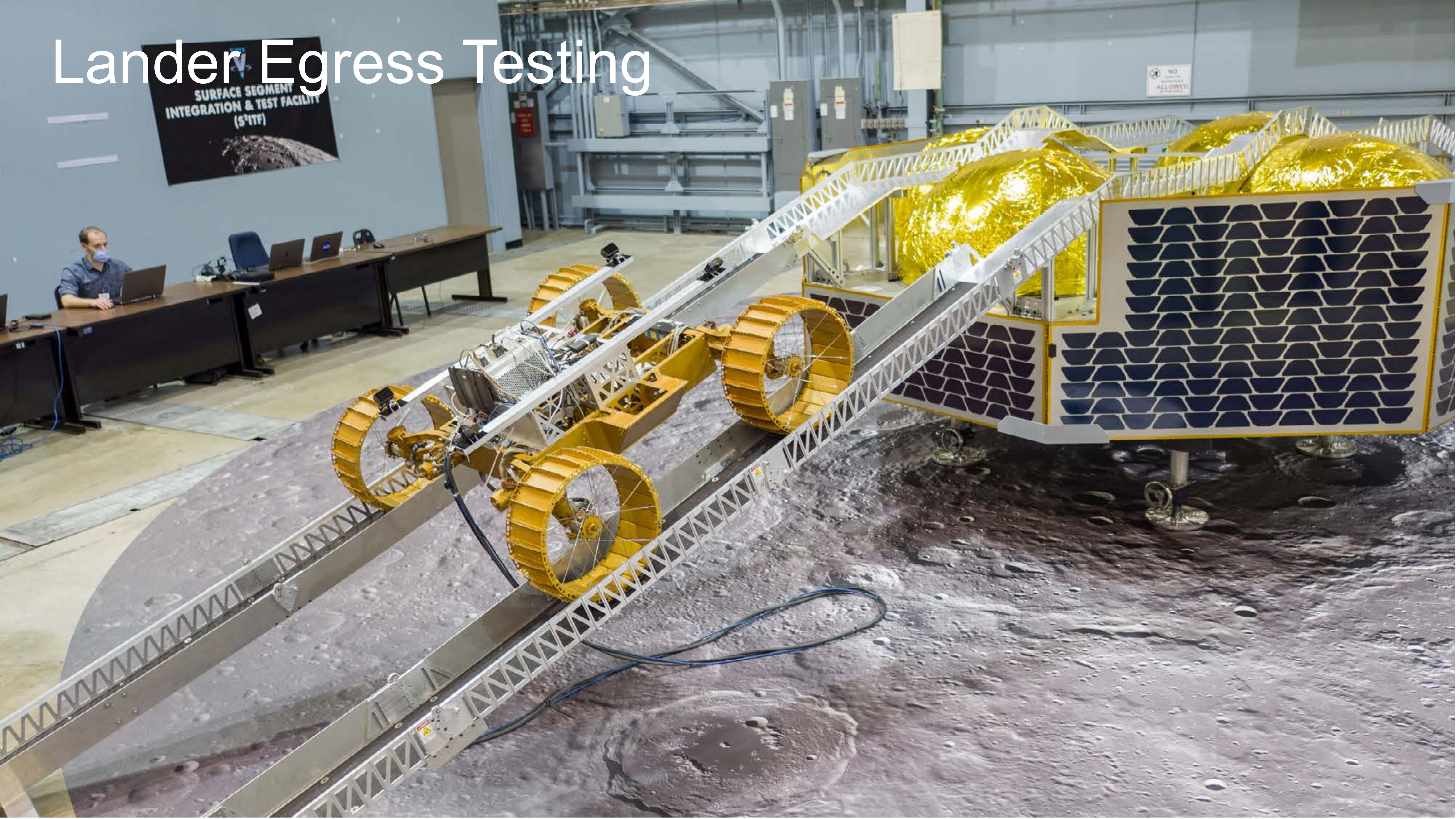


Entrapment Testing

Slip Testing

Crater Traversal Testing

Lander Egress Testing



Mobility Risk Assessment*

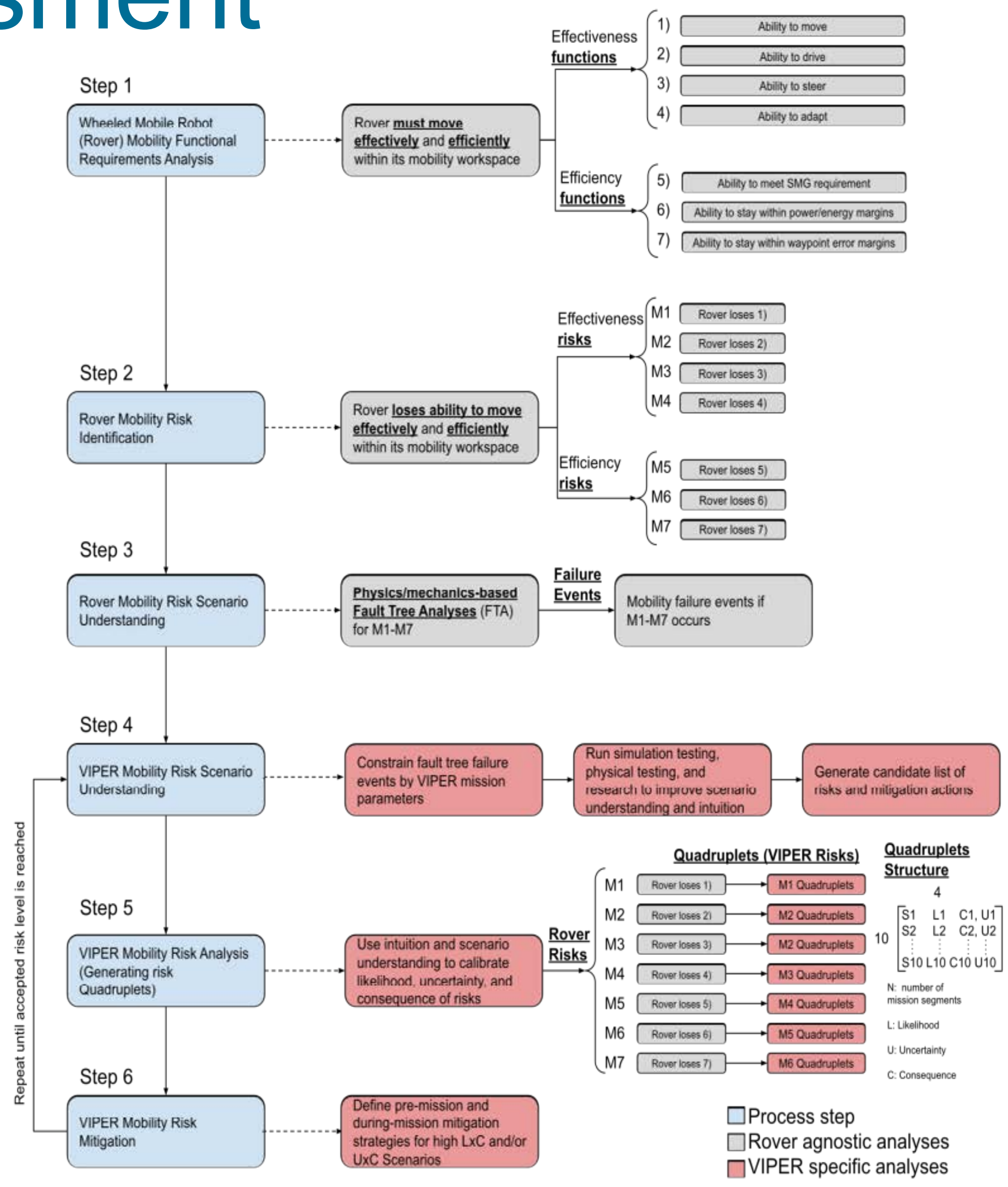
Mobility Fault Classes

- Actuation
- Controller
- Sensing
- Structure
- Terrain property
- Wheel-soil interaction

Fault Tree Analysis

- Physics and mechanisms
- Identify failure events/cascades
- Identify gaps (SW, controls)

*Performed by ProtoInnovations, LLC as part of a NASA STTR Phase 2 sequential award



Questions ?